5th High Power Targetry Workshop

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Book of Abstracts

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Welcome Address

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Spallation Source Facilities

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The world has seen three new spallation neutron source facilities become operational over the past decade. Two short-pulse, mercury target, mega-watt class sources – the SNS at ORNL, and the JSNS at JPARC – joined the continuous wave MW source SINQ facility at PSI that is now in its second decade of operation. The other new source now online is the modestly powered but innovative ISIS TS-2 at RAL, built complementary to the venerable TS-1. At only 32 kW, TS-2 is a product of a more integrated design optimization approach for target, moderators, and reflector – along with sharply defined neutron performance metrics for the associated neutron science instruments. Soon the operating facilities will be joined by the 100 kW CSNS in Dongguan, China and the 5 MW ESS in Lund, Sweden. Design features, performance characteristics and operating challenges of these and other spallation sources will be broadly compared in this talk. While mission requirements and funding sponsor expectations vary from site to site, a lesson from TS-2 is that high neutron source performance is possible without high power. For this workshop, discussion on the challenges and approaches of target-source design to optimize science performance will be a theme; this talk aims to lay some ground in the spallation source arena.

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Survey of Target Facility Landscape: Neutrino Beam Facilities

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An overview is given of the status and plans for the three currently operating neutrino beam facilities (T2K at JPARC, NUMI and BNB at FNAL). Several proposed facilities (LBNE, CENF, NUSTORM, LBNO, ESSnuSB) are also described.

Summary:

An overview is given of the status and plans for the three currently operating neutrino beam facilities (T2K at JPARC, NUMI and BNB at FNAL). Several proposed facilities (LBNE, CENF, NUSTORM, LBNO, ESSnuSB) are also described.

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Radioactive Ion Beam Facilities – High Power Target, Current status and Future Directions

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Radioactive ion beams are a challenge to produce because of their short half-life they have to be produced on-line. In the on-line isotope separation (ISOL), the isotopes are produced by nuclear reactions in a thick target material where the fragments come to rest embedded in the target material. The target container is closely coupled to an ion source, allowing them to be quickly turned into an ion beam that can be mass analyzed and delivered to an experiment. To enhance the release of the desired isotopes the target is operated at the highest "acceptable" temperature.
The future frontier of the ISOL technique is to increase the Radioactive Isotope Beams intensity by many orders of magnitude in order to satisfy challenging experiments such as Rn-EDM, Fr-PNC… for example. Several proposals, EURISOL, SPIRAL-2, CARIF, RISP, ISOL@MYRRHA and ARIEL will be reviewed in light of the high power target aspects.
The most direct method to increase the RIB intensity is to increase to the driver beam intensity. This can be accomplished to a certain degree, by using composite targets and high power dissipating target containers. This is accomplished by the TRIUMF-ISAC high power target which is capable of dissipating up to 20 kW of beam power, using a combination of high effective thermal conductivity target materials and enhanced radiative cooling of the target container. Beyond this point, radiative cooling alone is not sufficient and a more complex dircect cooling of the ISOL target has to be developped sucessfully.
High radioactive ion beam intensity can be obtained by an indirect ISOL target method. Secondary beams (neutrons or photons) produced by the interaction of a high intensity primary beam onto a converter target are used to induce fission on fissile target material, (U and Th). Decoupling the power deposition allows the operation of the ISOL-target at much lower power while the converter can be cooled efficiently without affecting the ISOL-target temperature and consequently the radioactive atoms overall release efficiency.
While the indirect ISOL target method can reach several hundred of kW to MW driver beam power, it uses only the fission nuclear reaction mechanism, limiting somewhat the radioactive ion beam to fission products.
New directions for direct ISOL targets, such as refractory powder, liquid metal targets capable of sustaining primary beam intensity in the MW region will be presented.

Summary:

The concepts and technical challenges of generating intense radioactive ion beams from ISOL target irradiated with high intensity proton beam are discussed.
The evolutions of the target design for high beam power dissipation over the past 20 years at existing ISOL facilities are reviewed.
Review of the future directions of the ISOL facilities to increase the Radioactive Isotope Beams intensity by many orders of magnitude in order to satisfy challenging experiments is presented.

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Survey of Target Facility Landscape: Accelerator-based Materials Irradiation Facilities

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Materials irradiation facilities based on accelerators are usually secondary facilities taking profit of accelerators driven by other main application (i.e. spallation sources). As a consequence the measured irradiation effects on the materials can be very different and, in some cases, hardly comparable between them.

Presently, the accelerator-based materials irradiation facilities designed from the very beginning based on the materials requirements are those related to the simulation of fusion-like irradiation effects on materials. To this family belongs IFMIF and other ones recently proposed and presently under discussion (ENS, DONES, FAFNIR, SORGENTINA).

In a very rough approach, the accelerator-based materials irradiation facilities can be classified based on the type of irradiation on the material, i.e. the accelerator particle is directly used to irradiate the material of interest (including facilities like some electron or ion accelerators) or facilities in which the accelerated particle is used to generate other particles that are used to irradiate the material (like MEGAPIE, MTS, MYRRHA, IFMIF or others).These last ones can be further classified based on the type of target (solid or liquid) or the accelerator power.

In this contribution a general overview of some of these different facilities will be made making special emphasis on the target characteristics of them, its main issues and their present status.

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Target Design Challenges Kick-off Talk

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Target challenges for the next generation of neutrino facilities

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High energy physics experiments often require a target to produce subatomic particles of scientific interest. In a typical particle accelerator, a high energy particle beam is fired at the target and the interaction results in the emission of neutrons or other particles of interest which in the case of charged particles are often refocused with magnetic fields. Many existing and proposed targets are designed to dissipate a significant amount of energy deposition that results from the incident particle beam. The trend has been for the incident beam power and in parallel the deposited power in the target to increase, so increasingly elaborate target designs have been proposed.
At lower power densities such as those experienced by the target of the T2K facility, a peripherally cooled solid target is employed. As deposited power density increases examples of internally cooled segmented targets such as those used in ISIS, CNGS and Numi-MINOS facilities demonstrate how segmentation provides a means to increase the heat transfer surface area and also reduce the thermal stresses. At the highest power densities as that expected for a future Neutrino Factory, rotating or flowing targets are proposed to reduce the peak power density experienced by constantly renewing

the target material. Rotating and flowing targets bring significant additional complexity, reliability, safety, handling and cost issues. In some cases they may be the only solution, however where it is possible to employ a stationary target that must be a preferable option.

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Thermal, Mechanical and Fluid Flow Challenges of the FRIB Primary Beam Dump*

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The Facility for Rare Isotope Beams (FRIB) under construction at Michigan State University is based on a 400 kW heavy ion accelerator and uses in-flight production and separation to generate rare isotope beams. The first section of the fragment separator houses the rare isotope production target and a primary beam dump to absorb unreacted primary beam. FRIB will use ion beams from 18O to 238U with about 300 kW remaining beam power needing to be absorbed by the dump. Based on the results of extensive R&D, a rotating water-cooled thin-shell metal drum was chosen as the concept for the FRIB beam dump. The design foresees a 70-cm diameter drum made of titanium alloy with a shell thickness of 0.5 mm. Flowing water is used to both cool the beam dump shell and absorb the power of the beam penetrating the drum wall and being stopped in water. The volumetric flow rate and the drum rotation speed chosen are 60 gpm and 400 rpm, respectively. Titanium alloys have been identified as good candidates for the drum material due to the high strength, low density and good corrosion resistance. Extensive thermal, mechanical and fluid flow analyses have been carried out for the beam dump interior and the Ti alloy drum shell in order to evaluate the beam dump high-power density capability for different primary beams from oxygen to uranium. The results of these studies will be presented.
* This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University

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Design, optimisation and operation of beam intercepting devices for CERN's fixed-target physics

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CERN is presently operating various particle producing targets and the associated infrastructure in its accelerator complex, including a neutron spallation source, an antiproton production targets, a neutrino target and various general-purpose primary targets for test beams and experiments. At the same time, devices of different types and characterized by high power density as well as high instantaneous power are under consideration for future CERN projects.
In this presentation the physics optimisation and engineering designs of these devices will be reviewed, highlighting the methods and procedures employed to guarantee a high level of reliability. The operation and the design of the respective target areas will also be addressed, providing perspectives for future potential installations.

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Discussion

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Thermo-Mechanical Analysis of ISIS TS2 Spallation Target

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A detailed thermal and mechanical analysis was carried out for the spallation target of the ISIS 2nd target station (TS2). The objective was to develop a better understanding of operating conditions in the target and to identify factors limiting target lifetime.
The TS2 target consists of a solid tungsten rod, with tantalum cladding to improve corrosion resistance. The cladding is bonded to the tungsten using the Hot Isostatic Press (HIP) process. FEA modelling was used to investigate the residual stress generated by HIPing. The simulated residual stress was large enough to cause yielding of the tantalum cladding. An experiment to measure the residual stress state in a HIPed plate has been carried out on the ISIS instrument ENGIN-X, and will be used to validate these models.
Steady-state and periodic components of beam induced stress were calculated using a transient FEA model. A bilinear material model with kinematic hardening was used to investigate the effects of periodic loading on the yielded cladding. Two different periodic load cases were considered: stress cycling due to beam pulses, and accident cases where the beam is tripped for several seconds or more. Fatigue life calculations were performed to assess the relative importance of the two cases.

Summary:

A detailed thermal and mechanical analysis was carried out for the spallation target of the ISIS 2nd target station (TS2). Factors considered include fatigue lifetime and residual stress due to hot isostatic pressing.

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Study of a new high power spallation target concept

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The ESS spallation target will be operating at 5 MW proton beam power. As the 5 MJ/s proton beam power is concentrated in 2.86 ms long 14 Hz pulses, the instantaneous power during each pulse impinging on target reaches 125 MJ/s. This large pulsed power condition poses a challenge in designing a robust and reliable target without sacrificing much of the neutronic performances.

In this report, we present a new rotating tungsten target concept that can be easily adapted to helium cooled and water cooled options. The proposed target has a simple geometric configuration with well-defined flow patterns. Both the helium cooled and the water-cooled options are investigated.

The purpose of this study is to show the technical feasibility of the new target concept. For the analysis, a number of numerical simulations have been performed using the particle transport code FLUKA and the multiphysics continuum physics simulation code ANSYS.

In this report, the particle energy deposition in the target, the thermomechanical characteristics of the target under proton irradiation, the decay heat analyses for accidental scenarios and the estimation of exothermic heat generation due to target material oxidation at high temperatures have been studied. The results indicate that the presented target concept have a good chance to keep its structural integrity, both for operational and accidental cases.

Summary:

In this report, we present a new rotating tungsten target concept that can be easily adapted to helium cooled and water cooled options. The proposed target has a simple geometric configuration with well-defined flow patterns. Both the helium cooled and the water-cooled options are investigated.

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High Power Targets and Performance Optimization versus costs or How much shall one pay for a useful neutron?

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The performance of a spallation neutron source depends on the underlying physics, its engineering and available technologies. However, the realization of a project and the operation of the facility will – in the real world - depend on the financial resources and political support. Funding will only be granted if appropriate sales arguments are given. A fashionable argument is to deliver a high power beam to the target to achieve high neutron fluxes, or better, higher power onto target than the other facilities. An increase of beam power will naturally result in higher neutron production rates of the spallation target. However, at the same time the higher beam power on a target system will impact its lifetime, complexity, downtimes and finally its costs (if its operation and the substitution of components are taken into account).
The second target station at ISIS impressively proved that the high power argument is not the only path to achieve high physics performance. The extensive use of simulations and smart engineering resulted in a high performing low power source which has set standards for future facilities.
Another criterion often used for the comparison of neutron sources is the neutron flux or brightness at the surface of a moderator. Important parts of the sources such as the neutron guide system and the shielding are completely disregarded if such a definition is used. If this criterion would be true ISIS TS2 could never perform well, if compared to existing MW sources. Likewise, using the flux of 'useful neutrons' at an instrument as a measure of performance could be misleading since it disregards background issues.
A fair performance comparison has to take into account all operation aspects, such as availability, background and neutron flux at the instruments sample position, appropriately weighted. With the availability of large computer resources it has become possible to consider all integral parts of a neutron source in simulations – from the target, to moderators, neutron guides, collimation systems and its appropriate shielding for background reduction at the instrument sample position. Hence performance studies of a source using several different figures of merit become possible.
At PSI the target development culminated in the operation of the liquid metal Lead Bismuth eutectic (LBE) target MEGAPIE. During its operation from August until December 2006 its advantage over the standard heavy water cooled target with respect to neutron production was clearly demonstrated, but at the same time also higher background was found. The higher overall costs for the liquid metal target with its ancillary systems together with its larger hazard potential and the lower lifetime

finally lead to the decision to continue using the heavy water cooled Cannelloni targets. However, MEGAPIE triggered a re-design of the water cooled target and pushed its performance.
In this talk we will outline the high power target development strategy of PSI and emphasize the need of simulation strategies, encompassing the facilities from the proton beam down to the detectors of the neutron instruments, to achieve the maximum performance under the given physical and economical boundary conditions.

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Discussion & wrap-up

HPTW Poster Session & Reception - Board: 305 / **133**

Assessment of the beam–target interaction of IFMIF: A state of the art

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The main requirement for an efficient and safe operation of the IFMIF plant is the stability of the Li jet. The stability is related to the thermohydraulic behaviour and can be affected by the beam–target interaction. The waviness of the jet must stay within rather narrow limits to protect the backwall from beam impact and to maintain stable irradiation conditions in the test modules. Thermal and momentum transfer of the beam may destabilize the flow structure, cause shock waves and increased evaporation or aerosol formation. Different aspects of beam interaction have been analyzed in the past, but a comprehensive assessment is still lacking. This contribution provides an overview of the IFMIF related beam–free lithium surface interaction studies including a description of the underlying basics. As it comes out from numerical analyses that the impact of thermal expansion and of the momentum transfer caused by the beam are still small enough to be ineffective for constructive interferences, beam–target interaction is not to be expected to have a critical impact on jet stability.

Summary:

This contribution provides an overview of the IFMIF related beam–free lithium surface interaction studies.

HPTW Poster Session & Reception - Board: 401 / **20**

Uniform irradiation of an extended target by high power beam.

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As part of the Accelerator Driven Subcritical Reactor project at BNL, high power beams are crucial to increase the neutron production of the spallation target. To minimize the stresses on the target and on the vacuum window, which separates the optical elements of the beam delivery system from the target region, we propose to expand the beam and uniformly distribute it over the target area. In this talk we will present a well proven method which uses higher order beam optics to accomplish beam uniformity and also allows to control the beam halo along the delivery line.

HPTW Poster Session & Reception - Board: 502 / **22**

Status of the FAIR pbar target and separator

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In the future FAIR facility at GSI in Darmstadt, Germany, a multitude of experiments with an antiproton beam is foreseen. It is planned to produce these antiprotons in a collision of a primary proton beam with a metal target. A Ni rod will be bombarded with a pulsed beam of 29 GeV protons with an intensity of 2.5E13 ppp and a repetition rate of 0.2 Hz. Directely after the target the antiprotons will be focussed by a magnetic horn operated with an current of 400 kA. In the proceeding magnetic separator antiprotons with an energy of 3 GeV (+-3%) will be selected and transported to the collector ring for cooling. The setup of the target and separator area, including radiation protection issues, will be presented.

Summary:

The status antiproton production target for the future FAIR facility will be presented.

HPTW Poster Session & Reception - Board: 202 / **53**

Beryllium material tests: HiRadMat windows and NOvA fins

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Beryllium is currently widely used in various accelerator beam lines and target facilities as material for beam windows, and to a lesser extent, particle production targets. With plans to increase beam intensities in future accelerator facilities, such as the PIP-II driven Long Baseline Neutrino Experiment (LBNE) at Fermilab, it is essential to take full advantage of the high temperature/strain rate plastic response of beryllium and identify material dynamic limits to avoid compromising particle production efficiency by limiting beam parameters. As a result, an experiment is being designed to investigate the failure mechanisms, limits and flow behavior of several commercial grades of beryllium exposed to intense pulsed proton beams at CERN's HiRadMat facility. The main objectives of this investigation, overview of the experimental set-up, and expected measurements and findings will be presented. A long term in-beam test of Beryllium is also planned using the NOvA MET-02 target. Preparations for inserting beryllium fins in the target will be presented including thermal and structural simulations of beam heating and physical testing using the MET-02 target components.

HPTW Poster Session & Reception - Board: 301 / **57**

Lead Bismuth Free Surface Target for High Intensity Proton Beam Application

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A Lead-bismuth cooled accelerator driven system (ADS) is considered as a promising option for the transmutation of long lived nuclear waste into short lived or stable isotopes. In this type of reactor a subcritical core is used receiving the required neutrons for the nuclear reaction by spallation using a high power proton beam from an accelerator. At the entry point of the reactor pool where the beam impinges on the surface of the liquid metal, which simultaneously acts as the target material, special construction effort is indispensable to handle the high heat production.
In order to demonstrate the ADS concept, the Multi-purpose hybrid Research Reactor for High-tech Applications (MYRRHA) is currently under design at Mol/Belgium. One of the proposed targets for this reactor is a free surface target, based on a ring like liquid metal curtain, converging into a liquid metal jet by surface tension effects, and thus forming an inner and an outer free surface. The inner surface is then subjected to the 2.4MW proton beam, while the curtain maintains the separation between beam line and reactor pool.
A near full scale prototype of this target design has been set up and experimentally investigated at the Karlsruhe Liquid Metal Laboratory (KALLA) at the Karlsruhe Institute of Technology (KIT). Measurements at different flow rates of up to 30m^3/h show a stable surface in a wide range of operating conditions. In addition, the exact inner and outer shape of the conical surfaces were detected by image processing and depth of field information. Comparison with numerical precalculations using commercial CFD code Star-CD and Star-CCM+ show a very good agreement of experimental and numerical data.

HPTW Poster Session & Reception - Board: 201 / **52**

Behaviors of transmutation elements Ca, Ti, Sc in ferritic-martensitic steel under mixed spectrum irradiation of high energy protons and spallation neutrons

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Ferritic-martensitic steel F82H was irradiated in a mixed proton-neutron spectra in the Swiss spallation neutron source SINQ up to 20.3 dpa at 345℃. Atom Probe Tomography (APT) investigations were performed in order to study the atomic scale evolution of the microstructure of the F82H steel under irradiation.
The irradiation led to the production of about 370 appm of Ca, 90 appm of Sc and 800 appm of Ti. APT experiments revealed that regardless their low bulk concentrations, the spallation products are involved in the microstructural evolution of the steel under irradiation: formation of radiation-induced clusters, segregation at the dislocation loops and alteration of the microchemistry of carbides.
A quantitative description of the observed features will be presented and results will be compared with TEM data of the literature obtained on the same steel and under similar irradiation conditions.

HPTW Poster Session & Reception - Board: 110 / **110**

Design and test of a graphite target system for in-flight fragment separator

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A graphite target system to produce rare isotope beams using in-flight fragmentation method has been designed for the rare isotope science project in Korea. A main primary beam to bombard the target is 238U in the energy of 200 MeV/u with the maximum power of 400 kW, in which beam power deposit on the target amounts up to 100 kW. A multi-slice target concept was adopted to enhance the radiation cooling effect. A finite element program ANSYS was used to analyze thermo-mechanical behavior of single and multi-slice targets. To validate the design, electron beam at the energy of 50 keV was used to test a single slice target. A good agreement of hot spot temperature was achieved between simulation and measurement. Results of simulation and electron beam simulations will be presented along with a plan to test multi-slice targets.

HPTW Poster Session & Reception - Board: 104 / **82**

A Feasibility Experiment of a W-powder Target

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The development of high-power targets constitutes a key R&D activity for future facilities presently under study like the Neutrino Factory, the Muon Collider or the upgraded high-power super beams for long-baseline neutrino experiments. The choice of materials to sustain the proposed beam power ranging up to (Multi-) MW levels is not trivial. Granular solid targets have been proposed and are being studied as candidates for such high-power target systems. In the recently commissioned HiRadMat facility of CERN, a feasibility experiment of a tungsten powder target was performed. The experiment was designed to explore for first time the impact of a high-power proton beam on a static powder target in a thimble configuration. The instrumentation of the experiment was based on remote high-speed photography as well as on laser - doppler vibration measurements of the target containers. Highlights of the results from the experimental findings are presented in this paper.

HPTW Poster Session & Reception - Board: 402 / **80**

SEM Grid Profile Monitors for Megawatt Proton Beams

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Profile Monitors providing precision measurement of beam profile distributions are essential for transport and targeting of high intensity proton beams. We describe here the SEM grid monitors developed for the 0.4 – 0.7 MW NuMI proton beam, along with the development process leading to the current monitor design. We also provide details of their utilization in the NuMI beam, along with extensive performance results. Finally, we provide design and performance details to date for monitors which should work well in 2+ MW proton beams.

HPTW Poster Session & Reception - Board: 205 / **81**

Mu2e Target Station design and radiation levels

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One of the main parts of the Mu2e experimental setup is its Target Station in which negative pions are generated in interactions of the 8-GeV primary proton beam with a tungsten target; a large-aperture 5-T superconducting production solenoid (PS) enhances pion collection. The heat and radiation shield (HRS) is a 33 ton water-cooled bronze shield which protects the PS coils and the first TS coils from interactions from the production target located inside the PS.The HRS protects the PS and the first TS coils; the beam dump absorbs the spent beam. In order for the PS superconducting magnet to operate reliably the sophisticated HRS was designed and optimized for the performance and cost. The beam dump was designed to both accumulate the spent beam and keep its temperature and

air activation in the hall at the allowable level. Comprehensive MARS15 simulations have been carried out to optimize all the parts while keeping the maximum muon yield. To determine the magnitude of the DPA damage effect on the residual resistivity ratio RRR) as well as the annealing cycle of PS, calculations have been done involving recent KEK measurements with Al and Cu samples. Prompt and residual radiation dose levels in and outside the Mu2e building are determined. MARS15 results on neutron fluxes and energy spectra are compared those from the MCNPX code. Results of simulations of critical radiation quantities and their implications on the overall Target Station design will be discussed.

HPTW Poster Session & Reception - Board: 105 / **85**

Three tier blistering tolerant neutron target for iBNCT by using 80kW proton linac.

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An accelerator-based BNCT (Boron Neutron Capture Therapy) facility is being constructed at the Ibaraki Neutron Medical Research Center, Japan. It consists of a proton linac of 80kW beam power with 8 MeV energy and 10mA average current, a beryllium target, and a moderator system to provide an epi-thermal neutron flux enough for patient treatment. The technology choices for this present system were driven by the need to site the facility in a hospital and where low residual activity is essential. The maximum neutron energy produced from an 8 MeV-proton is 6 MeV, which is below the threshold energy of the main nuclear reactions which produce radioactive products. The down side of this technology choice is that it produces a high density heat load on the target so that cooling and hydrogen aniti-blistering amelioration prevent sever challenges requiring successful R&D progress. The precise in-situ observation using polarized long distance microscopy with proton beam irradiation presents the performance of hydrogen storage alloys. Diffusion bonding method of Be, hydrogen storage alloy, Cu is also developed. The nucleate boiling method is applied. This solid neutron target is manufacturing and will be installed in this summer shutdown period.
The latest design of the target and moderator system shows that a flux of 4×10ˆ9 epi-thermal neutrons / cm2 / sec can be obtained. This is much higher than the flux from the existing nuclear reactor based BNCT facility at JAEA (JRR-4).

Summary:

An accelerator-based BNCT (Boron Neutron Capture Therapy) facility is being constructed at the Ibaraki Neutron Medical Research Center, Japan. It consists of 4.5MW/mˆ2 heat density, a three tier blistering tolerant Be neutron target with nucleated boiling region water cooling. This target is manufacturing and will be installed in this summer shutdown period.

HPTW Poster Session & Reception - Board: 511 / **108**

New Sorgentina Fusion Source (NSFS) Experimental Facility Supporting Materials Research

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Within the framework of fusion technology research and development, a neutron source has long been considered a key facility to perform irradiation tests aiming at populating materials engineering database – supporting DEMO reactor design and licensing. New Sorgentina Fusion Source (NSFS) has been proposed taking advantage of well-established D-T neutron generators technology, properly scaled in order to attain a bright source of some 1015 n/sec - with an actual 14 MeV neutron spectrum as relevant feature. Ion beams of 30 A are produced and accelerated up to some 200 keV energy. Present design envisages ion generators and extraction grid technology employed in neutral injectors currently utilized at large experimental tokamaks. Then deuterium and tritium ion beams are delivered to the target impinging on a hydride thin layer which is on-line D-T reloaded. Metal hydride is continuously re-deposited preventing layer from being sputtered and increasing installation load factor. Large and fast rotating target is conceived to enhance heat removal - coping with thermal transients and mechanical loads. Design features achieve high performances withstanding elevated heat flux of some tens kW/cm2 and significant thermal fatigue concerns. Main facility characteristics are provided, as well as target thermal and mechanical issues.

Summary:

Fusion spectrum relevant neutron source is perceived as major facility within the framework of R&D supporting DEMO reactor. Proven technology solution for bright neutron source is presented, utilizing scaled D-T neutron generators together with accelerators used in neutral injector systems at large tokamaks. High power density issues in rotating target design are presented as far as fast thermal transients are concerned and related thermal fatigue issues.

HPTW Poster Session & Reception - Board: 403 / **109**

Machine Protection Strategy for the ESS Target Station

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The ESS linear accelerator will deliver a 5 MW, low-emittance proton beam directly to the target station. To limit power density, a transport line expands this beam to centimetre scale and rasters this expanded beam across the target surface. This technique produces a reasonably uniform current density that enables a five year service life for the rotating tungsten target and a 6 month service life for the upstream proton beam window. Conversely, the beam's low emittance allows an errant spot size small enough to damage target station components within a single 2.86 millisecond pulse. A suite of instrumentation systems located within the target monolith and also upstream in the transport line will detect errant conditions and via the Beam Interlock System, suppress beam production. This presentation will introduce the primary causes of damaging beam properties, and describe the measurement techniques that will detect them promptly enough to mitigate component damage.

HPTW Poster Session & Reception - Board: 303 / **102**

Jet Flow Target Module Design, Analysis, and Testing

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The Spallation Neutron Source at the Oak Ridge National Laboratory produces neutrons by striking a target containing mercury with a pulsed proton beam. Examination of used targets shows that the innermost surface of the vessel where the proton beam strikes has a significant amount of damage due to mercury cavitation. The target also has an outer thin window flow channel which does not show significant cavitation damage. This lack of damage has two possible causes; the flow condition of the mercury and the thin width of the flow channel. Previous testing as LANSCE has also shown a link between flow condition and cavitation damage.
The target vessel design was modified to improve the flow condition on the inner surface of the vessel. A new design has been developed which diverts some of the bulk mercury flow into a wall jet which sweeps over the inner surface. Numerical simulations were used to develop a target design which balanced the jet flow and bulk mercury flow and provided a stable wall jet. The final design produces a flow condition across the inner surface of the target wall which mimics the near-wall velocity distribution in the channel where no significant damage has been found.
A test apparatus using water flowing in an acrylic vessel has been used to verify the predicted flow. Water allows for visual tracking of bubbles introduced into the flow. High speed videography of these bubbles has shown that the jet flow velocity agrees within 10% of the values predicted by simulation.

HPTW Poster Session & Reception - Board: 208 / **103**

A LIFETIME ESTIMATION OF THE IFMIF LITHIUM TARGET BAYONET BACKPLATE BASED ON PSEUDO-TRANSIENT ANALYSIS OF IRRADIATION-INDUCED SWELLING EFFECT

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In the framework of European fusion activities, a high flux neutron source is considered an essential device for testing candidate materials under irradiation conditions typical of future fusion power reactors. To this purpose, IFMIF (International Fusion Materials Irradiation Facility) project represents an important option to provide the fusion community with a source capable of irradiating materials samples at a rate of up to 20 dpa/fpy in a volume of 0.5 l. This is achieved by bombarding a high-speed liquid lithium target with a 10 MW double deuteron beam which yields a 14 MeV-peaked neutron spectrum. Within the engineering design work of the IFMIF/EVEDA project, which was concluded in half 2013, ENEA was in charge of the design of the lithium target system based on the so called bayonet backplate (BP) concept, which foresees the possibility to periodically replace only the most irradiated and thus critical component (i.e., the backplate) while continuing to operate the rest of the target for a longer period. With the objective of estimating the lifetime of the BP, a pseudo-transient calculation simulating one year of full-power operation has been performed by imposing a non-uniform neutron-induced volumetric swelling strain which evolves in time as a linear function of the accumulated displacement damage (dpa) according to available literature experimental correlations. Dpa damage distribution and time rate have been calculated by ENEA in the framework of an extensive neutronic analysis of the target system carried out through the MCNP transport code. The stress field evolution resulting from the increasing swelling deformation has been obtained through an uncoupled thermomechanical analysis carried out by the University of

Palermo using a qualified finite-element code which takes into account all thermal and mechanical loads applied to the system during normal operation.
In this paper, the results of the above analysis are presented and an estimation of the BP lifetime due to swelling effect is given on the basis of ITER design rules criteria. It is found that, although the bulk structure of the BP is expected to survive several months of continuous irradiation, a further improvement of the system design is suggested in order to achieve an optimized configuration.

HPTW Poster Session & Reception - Board: 109 / **106**

High-power powder-flow target for radioactive ion beams production

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Worldwide several efforts are underway to increase the intensities of radioactive ion beams at an ISOL facility by several orders of magnitude. One of the approaches is based on increasing the power of the primary beam on target. For this, issues have to be solved on target design and target material, which should be capable of withstanding reliably high beam-power deposition over long periods of time. This becomes especially important at a facility such as ISOL@MYRRHA, since the scientific program of this envisaged facility is based exclusively on experiments requiring long periods of operation without interruption.

This presentation will discuss the concept developed at SCK•CEN for a high-power ISOL target for the production of radioactive ion beams at next-generation proton-based ISOL facilities. The concept is based on the flow of refractory-powder material under the continuous irradiation with a proton beam. Results of our feasibility study will be presented covering multiple aspects: particle-flow calculations, mass-flow rates, powder-density distribution, beam-power deposition, temperature profile, in-target production rates calculations, release-efficiency analysis, expected yields and overall expected performance of the system.

The main advantages of this concept, as concluded from the feasibility study, are: the possibility to increase the primary-beam power on target to unprecedented levels, faster release of the produced isotopes, the large variety of the produced RIBs since any refractory compounds can be used, and the expected long operation periods, increasing the overall RIB production at the facility and reducing the radioactive waste inventory.

EURISOL, with its high primary-beam intensities going to powers in the Megawatt range, is another interesting project to apply this target concept.

HPTW Poster Session & Reception - Board: 209 / **107**

A Fusion Materials Irradiation Test Station at the Spallation Neutron Source

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It has long been recognized by the nuclear materials research community that facilities suitable for irradiation studies relevant to envisioned fusion power systems are lacking. Therefore, efforts are underway at the Spallation Neutron Source (SNS) to design an irradiation facility at the beam entrance region of the SNS target module for materials science research in support of fusion energy technologies. The unique mixed spectrum of high-energy protons and spallation neutrons at the SNS permits exposure to several different irradiation parameters of interest to the fusion materials community. For example, since the He production rate is heavily dependent on the proton fluence, the He production rates can be customized for each experiment; with He gas production to displacement ratios ranging from 13-75 appm He/dpa for steel and 30-98 appm He/dpa for SiC. The current design of the Fusion Materials Irradiation Test Station (FMITS) consists of two specimen-containing tubes along the front of the SNS target module located above and below the vertical mid-plane. Each specimen tube contains an inner tube surrounded by a water-cooled jacket and an inner tube that is cooled by flowing mixed inert gases, which are used to establish and maintain the target irradiation temperature. Thermal analysis indicate maximum specimen temperatures ranging from 650℃ to 1300℃ could be achieved using the mixed-gas temperature control system. This poster describes some of the basic features of the FMITS irradiation assembly, including hardware configuration and achievable irradiation parameters.

HPTW Poster Session & Reception - Board: 304 / **104**

Simulations of Particle Impacts on Beam Intercepting Devices and Methods for an Experimental Characterization

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In recent years, state-of-the-art numerical methods, involving the use of Autodyn and LS-Dyna wave propagation codes, have been developed at CERN and at Politecnico di Torino in order to simulate the impact of a particle beam on solid accelerator devices such as collimators, windows, targets, dumps and absorbers. These methods were adopted by the authors in 2011 to analyze the consequences of an asynchronous beam abort on LHC Tungsten Collimators (TCT). In order to validate the material constitutive models, in 2012 and 2013 a vast characterization campaign has been launched, entailing advanced beam impact tests in the HiRadMat facility and high-speed mechanical measurements at Politecnico di Torino with the Hopkinson bar setup. The experiments confirmed the effectiveness of numerical methods to reliably predict beam-induced damages, also allowing to improve the material models. New simulations were then performed, adopting the refined material models and the updated accident scenarios; damage limits were also redefined, to identify the threshold of incipient plastic damage on the tungsten jaw.

HPTW Poster Session & Reception - Board: 203 / **62**

Materials in Extreme Environments at ELI-NP

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The ELI-NP (Extreme Light Infrastructure -Nuclear Physics) facility, currently under construction in Magurele, Romania, will make possible experiments with high power lasers with peak powers of 100 TW, 1PW and 10PW.
One of ELI-NP research direction will focus on the field of materials in high radiation fields, temperature and pressure conditions, taking advantage of the ultrashort time scales of secondary radiation pulses and the relatively broadband spectrum of radiation, complementary to the traditional nuclear physics research laboratories. Further specificity of the proposed experimental environment for tests at ELI-NP is that it simultaneously provides two or more types of radiation at the same time and on the same target. The planned radiation beams at the beginning at the ELI-NP operation will be: photon radiation (maximum energy of 19 MeV and maximum intensity 10ˆ9 photon/pulse), laser driven electron beam (maximum energy 2 GeV and maximum intensity 10ˆ8 e/pulse), laser driven proton and ion beams (maximum energy 100 MeV and maximum intensity 10ˆ9 p/pulse) and laser driven neutron source (maximum energy 20 MeV and maximum intensity 10ˆ7 n/pulse).
The study of materials behaviour in extreme environments will be a central topic, with a direct application to the development of accelerator components, understanding of structural materials degradation in next generation fusion and fission reactors or the shielding of equipment and human missions in deep space missions. Testing of novel materials for accelerator components at the future high–power facilities like FAIR, High Lumi-LHC, FRIB, neutrino factories and ESS in conditions of radiation, temperature and pressure reproducing operation scenarios would be possible by using "cocktails" of laser driven particles and laser induced shock waves. ELI-NP through experimental areas E5 (1PW at a repetition rate of 1Hz) and E4 (100TW at a repetition rate of 10Hz) offers an unique testing facility complementary to accelerator irradiation. The availability of two high-intensity short-pulse lasers would enable pump-probe experiments using laser based diagnostic enabling structural degradation studies during irradiation on a much finer time scale.

HPTW Poster Session & Reception - Board: 204 / **64**

Nano-Indentation study of radiation damage induced by swift heavy ions in HOPG and polycrystalline graphite

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Operation under intense radiation damage conditions and thermo-mechanical loads is common for both targets and beam protection components for high power particle accelerators like FAIR (Facility for Antiproton and Ion Research) which is currently under construction in Darmstadt, Germany. To ensure safe operation and less frequent maintenance shut-down's related to beam catchers and targets, optimized material and design solutions are needed. Due to its low atomic number combined with very good and stable thermo-physical properties and with its high radiation hardness, graphite and other carbon based materials are possible candidates for beam dumps and targets. We used nano-indentation to characterize the radiation induced embrittlement in carbon based materials. HOPG (highly oriented pyrolytic graphite) and high density isotropic graphite samples have been exposed to 3,6 MeV/u 197Au25+ and 4,8 MeV/u 238U29+ ion beams at the M-branch facility using fluxes of 5e8 ions/cm²s up to 2e10 ions/cm²s, at the UNILAC accelerator at GSI. Typical pulse lengths for 197Au25+ were 5ms @ 30Hz - 50Hz and 500µs @ 0,1JHz - 2Hz for 238U29+. Fluences between

1e11 ions/cm² and 5e13 ions/cm² were achieved. A general increase of young modulus and surface hardness with increasing ion-fluence can be observed for both HOPG and isotropic polycrystalline graphite samples.

HPTW Poster Session & Reception - Board: 302 / **68**

G-2 ANSYS Mechanical Simulation for Lithium Lens

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Lithium Collection Lenses were used to collect anti-protons for decades during the Tevatron collider run at Fermilab. This investigation looks at using the same Lithium Lens design for future use for muon production during the g-2 experiment at Fermilab; where thermal loading is much less per pulse, but the repetition rate is much higher. A transient ANSYS analysis was performed comparing the two cases. Results and failure modes are presented along with some special operating conditions that are possible with the g-2 timeline.

HPTW Poster Session & Reception - Board: 103 / **72**

LBNE 1.2MW Target Conceptual Design

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The Long Baseline Neutrino Experiment (LBNE) will utilize a proton beamline at Fermilab with 1.2MW power on target in the baseline configuration. A graphite target concept using a scaled version of the IHEP low energy target design was chosen to fulfill the design criteria. The proton beam was enlarged to a 1.7mm beam sigma compared to the 1.1mm beam sigma the IHEP LE target was originally designed for and target dimensions were scaled appropriately. Water cooling lines and target geometry have been optimized via thermal and structural beam heating simulations, and the final result is a target is predicted to operate successfully. The impact of scaling up the target on neutrino yield was shown to be minimal through detailed MARS15 simulations.

HPTW Poster Session & Reception - Board: 505 / **69**

Target Station Design for Neutrino Superbeams

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A conceptual design is presented for the target station and remote handling system of a multi-MW neutrino facility. This was originally developed for the EUROnu Super Beam study, which proposed a 4MW beam delivered to 4x 1MW pebble-bed targets operating in parallel. The target station was designed to cope with the unique demands of this 4 target arrangement, as well as challenges such as high activity and remote handling which are common to any high power facility. Although the EUROnu SB study has come to an end, many of the concepts developed here will be relevant to other current and proposed neutrino facilities.
EUROnu would have required construction of a completely new target station; this allowed every part of the facility to be designed and optimised from the ground up. The emphasis was on maximising uptime and ensuring safety, while minimising the costs of construction, operation and maintenance. The design concept was based on the target station of T2K, which was designed for comparable levels of beam power and activation and has been in operation for several years. The knowledge and practical experience gained from T2K were considered throughout the design process.

Summary:

A conceptual design is presented for the target station and remote handling system of a multi-MW neutrino facility, originally developed for the EUROnu Super Beam study.

HPTW Poster Session & Reception - Board: 508 / **90**

Radiological Calculations on the LBNE Neutrino Beamline

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The Long Baseline Neutrino Experiment (LBNE) will deliver a
high intensity neutrino beam from Fermilab to a
detector 1300 km away in South Dakota. The neutrino beam will be produced from the decays of pions and kaons generated
from a 120 GeV proton beam incident on a 95 cm long graphite target.
To operate this facility over a twenty year period at a proposed 2.3 MW beam power requires extensive radiological calculations during the design process. Radioactivation and shielding calculations on the LBNE target hall and decay pipe facilities will be presented. The input to these calculations are based on results from a simulation
using the MARS15 code.

HPTW Poster Session & Reception - Board: 509 / **95**

Tritium Mitigation for the LBNE Beamline

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The production of tritium is a radiological concern in the operation of the Long Baseline Neutrino Experiment (LBNE) beamline. This
experiment aims to send a high intensity neutrino beam from Fermilab to a detector located approximately 1300 km away in South Dakota. The high power 120 GeV proton beam incident on a 95 cm graphite target will produce significant amounts
of tritium in and around the target hall facilities.
Although sufficient shielding can
minimize the amount of tritium generated in the environment, tritium's mobility requires special care in designing the beamline facilities. Sufficient precautions can minimize the transfer to the enviroment of tritium generated in the concrete shielding.
Tritium which is either generated in or transfered to fluid or gasseous mediums needs to be either contained or released in a manner which will not violate any
State or Federal environmental regulations.
Presented will be an overview of the predicted impact of tritium on the LBNE beamline and the methods that will be used to manage the exposure of the environment.

HPTW Poster Session & Reception - Board: 510 / **94**

Proposals for ISIS Target Station 1 upgrade

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From the original vision over 30 years ago, ISIS has become one of the UK's major scientific achievements. It is a world-leading centre for research in the physical and life sciences at the STFC Rutherford Appleton Laboratory near Oxford in the UK. The suite of neutron and muon instruments gives unique insights into the properties of materials on the atomic scale. ISIS supports a national and international community of more than 3000 scientists for research into subject ranging from clean energy and the environment, pharmaceuticals and healthcare, through to nanotechnology and materials engineering, catalysis and polymers and on to fundamental studies of materials.
With the knowledge and computational tools now available it is widely believed that the useful neutronic output of the ISIS First Target Station (TS1) can be significantly improved. There is a current project to assess the feasibility of this proposal. The overall aim is to have the implementation phase of the project complete by 2019.
This poster will cover some of the proposals and work carried out as part of the feasibility phase of this upgrade project.

Summary:

An overview of some of the on-going work on the ISIS Target Station 1 upgrade project.

HPTW Poster Session & Reception - Board: 108 / **97**

Thermal Hydraulic Design of the Double-walled Mercury Target Vessel

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Cavitation damage of the target vessel wall which is caused by the pressure wave in mercury induced by the pulsed high power proton beam injection is the crucial issue for the development of the high power mercury target. Based on the analytical and experimental studies and also on the operational experiences of SNS, the effect of the rapid mercury flow to mitigate the cavitation damages seems obvious. In order to include this effect into the JSNS mercury target design, we applied doubled-walled structure to the beam window of the target vessel. The mercury flow velocity in the narrow channel between the double walls increases to almost 4 m/s, which should suppress the cavitation damages. In this presentation, the thermal hydraulic design of the double-walled target will be shown including the case of the failure of the inner wall.

HPTW Poster Session & Reception - Board: 207 / **96**

DPA Calculational Methodologies Used in Fission and Fusion Reactor Materials Applications

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Well-developed methodologies have been extensively applied to predicting radiation damage in materials for the neutron irradiation environments typically encountered in reactor test irradiations. Decades of reactor experience have resulted in standardized methods. An example is the ASTM standard dpa cross section for iron based reactor materials based on the traditional NRT-dpa model. Folding of calculated neutron energy spectra with neutron damage cross sections derived from ENDF/B evaluations as a function of accumulated neutron fluence is a typical application in reactors. Various dpa methodologies have been proposed in an attempt to correlate reactor irradiations in various neutron spectra and with the much higher damage rates in charged particle irradiations. Methods applied for neutron irradiation of reactor materials will be compared to methods used for charged particle irradiations. The basics of these techniques will be described, along with some of the limitations of the methodologies for predicting material behavior. The use of MCNPX in calculating the radiation environments, dpa, and gas production in both nuclear reactor and charged particle irradiations will be described.

HPTW Poster Session & Reception - Board: 501 / **19**

Operational Experience of a High-Intensity Accelerator-based Neutron Source Based on a Liquid-Lithium Target

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A prototype of a compact Liquid Lithium Target (LiLiT), able to constitute an intense accelerator-based neutron source was successfully tested for the first time with an intense 1.9 MeV, 1.3 mA (˜2.5 kW) continuous-wave proton beam. The high-power liquid-lithium target is designed to produce

neutrons through the 7Li(p,n)7Be reaction and to overcome the major problem of removing the thermal power generated by the proton beam at high intensity (1.91-2.5 MeV, >3 mA). Gold activation targets positioned in the forward direction show that the average neutron intensity during the experiment was ˜2×1010 neutrons/s. The device will be used to assess the feasibility of accelerator-based Boron Neutron Capture Therapy (BNCT) with a lithium target and for research in stellar and Big-Bang nucleosynthesis and Accelerator Driven Systems (ADS) material cross section measurements. The liquid-lithium jet acts both as neutron-producing target and as a beam dump, by removing with fast transport the thermal power generated by high-intensity proton beams. It has been designed to generate a stable lithium jet at high velocity on a concave supporting wall with free surface toward the incident proton beam (up to 10 kW). Of specific concern is the power densities created by the protons at the Bragg peak area, of the order of 1 MW/cm3 (volume power density), about 150 µm deep inside the lithium. Radiological risks due to the 7Be produced in the reaction will be handled though cold trap and appropriate shielding. Fire safety issues are taken care by multiple layers of passive and active safety devices.

HPTW Poster Session & Reception - Board: 101 / **18**

Design and Thermal-Hydraulic Performance of a Helium Cooled Target for the Production of Medical Isotope 99mTc

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99mTc, the daughter isotope of 99Mo, is the most commonly used radioisotope for nuclear medicine in the United States. Under the direction of the National Nuclear Security Administration (NNSA), Los Alamos National Laboratory (LANL) and Argonne National Laboratory (ANL) are partnering with NorthStar Medical Technologies to demonstrate the viability of large-scale 99Mo production using electron accelerators. In this process, 99Mo is produced in an enriched 100Mo target through the 100Mo(γ,n)99Mo reaction. This paper describes the design and performance (test results) of the helium-cooled Mo target to date. Modifications of the target size (diameter and length) continue toward an optimum configuration for isotope production maximization, but with volumetric heating as high as 33 kW/cc the cylindrical target has been segmented into disks to keep the peak heat flux under 1000 W/cm2. Changes in electron beam spot size and shape, also continually evolving toward an optimum for both production and cooling, impact of the design and performance of the target. The current design status and performance predictions are discussed.

HPTW Poster Session & Reception - Board: 206 / **88**

Post-Irradiation Examination Capabilities at PNNL Relevant to Target and Window Materials

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The Pacific Northwest National Laboratory has a number of facilities and capabilities that are relevant to post-irradiation examination of high power accelerator target and window materials such as graphite, beryllium, and Ti-base alloys. The Radiochemical Processing Laboratory contains a variety of shielded hot cell facilities routinely used for cask handling, experiment disassembly, visual inspection, gamma spectroscopy, metallographic sample preparation, chemical analysis, and thermal and mechanical property measurement. Small samples can be prepared in the hot cells to enable more specialized analyses in shielded gloveboxes and fume hoods including optical, scanning, and transmission electron microscopy, energy- and wavelength-dispersive x-ray spectroscopy, electron backscatter diffraction, x-ray diffraction, hydrogen and helium isotope assay, surface science such as Auger electron spectroscopy, x-ray photoelectron spectroscopy and Fourier transform infrared spectroscopy. Complementary radiological capabilities in the Materials Science and Technology Laboratory include additional scanning and transmission electron microscopes, a focused ion beam for micro-scale sample preparation, load frames for mechanical property measurements, immersion density apparatus, and autoclaves for corrosion testing. The poster will highlight relevant capabilities and provide examples of work from fission and fusion reactor materials irradiation experiments.

HPTW Poster Session & Reception - Board: 107 / **89**

PNNL Beam Window and Target Analyses

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In this presentation, PNNLs work on structural analysis, material selection and fabrication issues associated with the energy deposition of proton beams in representative windows and targets will be explored. Strategies to improve the survival of beam window and target designs under challenging energy deposition rates will be discussed. High power beam parameters can induce very high thermal cycling, thermal shock and stress waves that in combination with material damage effects due to the irradiation may eventually exceed the available strength and ductility of the material. The energy deposition and resulting thermal response and induced stresses and strains are computed using the ANSYS finite element code. PNNLs extensive experience in the design of test trains successfully irradiated in the Advanced Test Reactor will be reviewed with a focus on available irradiated material properties, cooling methods, and novel fabrication strategies. The presentation will address optimal combinations of material properties, window and target configurations and beam parameters that should allow for greater utility of the components under the extreme demands of high energy proton beam applications.

Summary:

Summary oral presentation (˜15-20 min) on PNNLs analyses with a focus on stress/strain results, material selection, rapid thermal cycling, irradiated material properties, cooling and fabrication related issues.

HPTW Poster Session & Reception - Board: 106 / **86**

The Sinuous Target

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We present the concept for a target material comprised of a multitude of interlaced wires of small dimension. The wires will be made of a thermal-shock resistant material, but will not be subject to stress accumulation due to their small size. The intrinsic bends of the wires will allow them to absorb the strain of thermal shock with minimal stress. The bulk of this material will have a dramatically lower bulk modulus than the bare material, greatly improving its resistance to thermal shock. Furthermore, the interlaced nature of the wires provides containment of any segment that might become loose. The small feature size enhances the healing ability of the material. Some concepts for use will be presented, including fabrication and cooling techniques.

HPTW Poster Session & Reception - Board: 503 / **42**

Radiation protection studies for the design of the CERN Neutrino Facility (CENF)

Author: Claudia Strabel[1]

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A short-baseline CERN Neutrino Facility (CENF) has been proposed in which a high-intensity 100 GeV proton beam with a beam power of up to 200 kW will be directed to a new fixed target complex in the North Area of the CERN Prévessin site. The target complex will be located underground at a depth of 15 m and contains, in addition to the production target itself, a focusing system, a decay tunnel and a subsequent beam dump & hadron absorber. The produced neutrinos will then be measured with a near and far detector both located within CERN territory at 460m and 1600m from the target, respectively.

In order to respect the applicable CERN radiation protection legislation regarding doses to personnel as well as the environmental impact, a full radiological assessment of the CENF facility has been carried out. Studies include expected prompt and residual dose rates in the various accessible areas of CENF as well as the effect of the stray radiation on the surrounding experimental and public areas. Furthermore, the risk due to activated air and the consequence of its release into the environment has been evaluated. Finally, studies on ground activation, radioactive waste zoning and radiation exposure of equipment have also been conducted. All studies are based on simulations using the FLUKA Monte Carlo particle transport code.

The results of the radiological assessment, which allowed a careful optimization of the CENF design with regard to radiation protection, will be presented.

HPTW Poster Session & Reception - Board: 102 / **43**

CENF target thermo-mechanical study

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The design of the target assembly for the proposed CENF neutrino facility is a challenging task due to the very strict physics requirements. The material chosen for the target is graphite, while a beryllium double pipe configuration is foreseen for the external containing structure. The assembly must be supported in cantilever and has to fully fit inside a focusing horn featuring a very narrow neck (24

mm diameter). A helium cooling system has been designed to insure reasonably low temperatures for the external structures (350-400 K) and to keep the target at a temperature of around 700-800 K in order to minimize the modifications of the mechanical properties due to radiation damage. A second design, adapted for a possible larger horn neck of 30 mm diameter has also been studied in order to evaluate and improve the feasibility as well as the working conditions identified in the first design.

HPTW Poster Session & Reception - Board: 507 / **77**

A High-Power Target system for the Production of Intense Muon Beams

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We describe a solenoid capture system suitable for producing an intense muon beam for eventual injection into either a neutrino factory storage ring or a muon collider ring. This arrangement allows for the capture and transport of muons of both charge states. An initial configuration featuring a low-Z solid target is envisioned for a 1-MW proton driver beam, while maintaining an upgrade path to 4-MW operation, perhaps with a liquid-jet target.

HPTW Poster Session & Reception - Board: 506 / **75**

Mu2e Production Target Remote Handling

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The CD-2 conceptual design for the Mu2e production target remote handling system will be a robotic machine that is capable of performing the target exchange autonomously. After entering the target hall from the side through a sliding/shielded door, the robot is being designed to perform the following tasks: locate and remove the target access window from the end of the vacuum chamber, place that window into a radioactive storage cask, reach forward 12 feet to remove the target from inside the vacuum chamber, place that target into the cask, retrieve a new target and reach out 12 feet again to install it into the vacuum chamber, retrieve a new access window and install onto the end of the vacuum chamber, then exit the room. These tasks are to be accomplished using a machine-vision guidance system, along with several motorized and pneumatically operated motions. The presentation will provide a detailed description of the robotic system design and will include many pictures from the 3D CAD model.

Focus Session 2: Radiation Damage and Material Limits / 61

RADIATION DAMAGE AND MATERIAL LIMIT: ILLUSTRATION OF A WAY TO CODIFY RULES WITH RCC-MRx CODE

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RCC-MRx, developed especially for Sodium Fast Reactors (SFR), Research Reactors (RR) and Fusion Reactors (FR-ITER) can also be used for components of other types of nuclear facilities. It has been consider for instance in the frame of a CEN-Workshop (CEN-WS 64 - Design and Construction Code for mechanical equipments of innovative nuclear installations) in order to develop, on its basis, the European code for the design and fabrication of mechanical equipments for ESNII (European Sustainable Nuclear Industrial Initiative) innovative nuclear installations.

The specific features of this current state of art nuclear design and construction code for mechanical components are:
• creeping damage is covered by the design rules responding to the needs of fast breeders and high temperature
• irradiated material is covered by the design rules responding to the needs of research reactors developed for the JHR project
• enlarged material selection range compared to material usually considered by others nuclear design and construction codes such as aluminum alloys, zirconium alloys, 9Cr ,
• manufacturing techniques such as neutron beam welding,….

Once introduced the application domain, main purpose and overall structure of the set of rules, the presentation focuses on the irradiated material design rules including:

- the background of these rules, linked with the changes in material behavior
- their content, in term of damages impacted,
- and the challenges to be met for their developments to other applications.

The conclusion highlights the potential benefits of these rules for the design and construction of components for the spallation and accelerator facilities.

Focus Session 2: Radiation Damage and Material Limits / 46

Dose Limit Philosophies Implemented at the Spallation Neutron Source

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The microstructures of components in nuclear systems exposed to high-energy particle radiation are altered during operation by various processes typically referred to as radiation damage. The microstructural damage in turn alters the mechanical properties of the component, usually in a deleterious manor manifested as a loss of ductility and fracture toughness. It is critical that components in nuclear systems maintain sufficient mechanical properties during operation to ensure proper operation and prevent component failure. Lifetime limits are typically assigned to components based on information from both radiation-effects experiments and pervious operational experience. At the Spallation Neutron Source (SNS) administrative lifetime limits for critical components have been established to minimize the risk of component failure and facilitate reliable neutron production. This talk will present the philosophy behind the dose limits for critical SNS components that are exposed to high-energy particle radiation during operation, along with administrative dose limits currently implemented at the SNS.

Focus Session 2: Radiation Damage and Material Limits / 119

Discussion-Design Limits

Focus Session 2: Radiation Damage and Material Limits / 65

Design and Development of a High Temperature Radiatively Cooled Tungsten Target for Mu2e

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The planned Mu2e experiment at Fermilab requires a high-Z production target to generate pions from an incoming 8kW proton beam. The refractory metal tungsten is an ideal target material since it is able to directly radiate the beam heat load to its surroundings without the need for a coolant, thus avoiding the cost of an active cooling circuit and greatly simplifying the remote target exchange process. The target must survive in a harsh environment that includes intense proton irradiation, continuous thermal cycling, and chemical attack by residual gasses in the vacuum. In addition, it must operate continuously at temperatures at least as high as 1500℃ in order to emit sufficient energy by radiation to achieve thermal equilibrium.
A test programme aimed at demonstrating the feasibility of this radiatively cooled target concept is underway. We present the latest results, in particular; ultra-high temperature thermal fatigue tests, oxidation lifetime at high temperature and low pressure, and emissivity/surface characterisation measurements. We describe the thermo-mechanical design of the target and its low-mass support system, together with the latest progress in prototyping of the refractory metal components.

Focus Session 2: Radiation Damage and Material Limits / 17

HiRadMat at CERN SPS - A dedicated in-beam test facility

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HiRadMat (High Irradiation to Materials), constructed in 2011, is a facility at CERN designed to provide high-intensity pulsed beams to an irradiation area where material samples as well as accelerator component assemblies can be tested. The facility uses a 440 GeV proton beam extracted from the CERN SPS with a pulse length of
up to 7.2 s, to a maximum pulse energy of 3.4 MJ (3*10ˆ13 proton/pulse).
The presentation will demonstrate the possibilities for research using this facility and showing examples of upcoming experiments scheduled for the coming beam period starting in Autumn 2014.

Focus Session 2: Radiation Damage and Material Limits / 118

Discussion: Design and Target Development

Focus Session 2: Radiation Damage and Material Limits / 39

Irradiation damage on material for FRIB project

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The Facility for Rare Isotope Beams (FRIB) is a new national user facility for nuclear science, funded by the Department of Energy Office of Science (DOE-SC) Office of Nuclear Physics, and under construction at Michigan State University (MSU), East Lansing, USA. FRIB will provide intense beams of rare isotopes by making use of an in-flight production technique employing a superconducting radiofrequency heavy ion linac and a large acceptance, high-resolution fragment separator. The first section of the fragment separator houses the rare isotope production target and a primary beam dump to absorb the unreacted primary beam. The production target is based on a radiation cooled multi-sliced rotating wheel made of graphite. The baseline concept for the beam dump is a rotating continuous-flow water-filled titanium-alloy drum. To keep the thermo-mechanical stresses at an acceptable risk level, the high-power production graphite target wheel and the water filled beam dump drum were designed to operate at appropriate rotational speeds (5000 RPM for the target and 400 RPM for the beam dump) in high-vacuum conditions. Ferrofluidic vacuum-sealed rotary feedthroughs were adopted for this task.
In addition to the high-power density challenge, continuous irradiation of the material with swift heavy ions will result in radiation damage of the material, leading to change in their structure and thermo-mechanical properties and limiting target and beam dump lifetimes.
During operation radiation damage may also compromise ferrofluidic feedthrough performance.
As part of the development work in support of the design of the FRIB fragment separator, graphite, Ti-alloys and Ferrofluidic Feedthrough were irradiated and post irradiation analyses were performed.
This talk will described irradiation setups and in-situ and the post irradiation techniques used to characterize material change. We will present results from tests performed with graphite, Ti-alloys and ferrofluidic feedthroughs at different fluences.

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University.

Summary:

This talk will cover radiation damage studies on relevant materials under high intensity swift heavy ion beams and associated equipment for Facility for Rare Isotope Beams (FRIB) project.

Focus Session 2: Radiation Damage and Material Limits / 45

Experimental investigation of beryllium: plans and current results within the RaDIATE collaboration

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Beryllium is one of the candidate materials for beam windows and target components in the new high intensity, multi-megawatt proton accelerator particle sources. An international research project Radiation Damage In Accelerator Target Environments (RaDIATE) was recently launched in order to explore radiation damage issues in materials under the relevant environment and investigation of beryllium covers a large part of this collaboration. Within this project, a micro- and nanoscale description of Be microstructure will be performed as a function of irradiation dose, temperature and impurity concentration. The combination of TEM experimental results (evolution of radiation defects), atom probe tomography data (evolution of impurities distribution) and micro-mechanical tests will contribute to the fundamental understanding of radiation-induced effects and prediction of the radiation response of beryllium as a material for windows and targets. Descriptions of the experimental program and the results of the current activities will be presented.

Focus Session 2: Radiation Damage and Material Limits / 63

Ion-irradiation induced degradation of thermo-mechanical properties of carbon-based materials

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This work summarizes our latest results on ion-induced degradation of thermal diffusivity and mechanical response of carbon materials for production targets and beam catchers applications in high power accelerator facilities. Investigated materials include graphitic grades like high-density isotropic graphite, flexible graphite and carbon- carbon composites. Irradiations have been performed at the M3 beamline at the UNILAC linear accelerator at GSI, Darmstadt with 131Xe, 197Au and 238U ions with energies between 709 Mev and 1.14 GeV.

It is shown that energetic heavy ion-induced structural defects result in an early reduction of thermal diffusivity of graphite. Impact tests using nanoindentation indicate also a radiation induced degradation of impact response and fatigue resistance of graphitic material. Swelling of the irradiated target material induces contours of increased stress at the edge of the beam spot. Thermal conductivity decrease leads also to increased thermal stress adding at the stress concentrators positions. These phenomena together with material embrittlement play the major role in target and beam catcher failure scenarios, during long term operation.

Focus Session 2: Radiation Damage and Material Limits / 100

Mechanical Test Techniques for Small Specimens

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Techniques for extracting mechanical property information from small volumes of material have been in existence for many years. A good fraction of the development has occurred in the radiation effects community due to a desire to limit exposure to radioactive material, and/or due to limited amounts of irradiated material. Some existing test methods continue to be refined, and new methods are continually being devised. At one end of the spectrum are miniaturized versions of standard mechanical property specimens such as tensile specimens and compact tension specimens. Typical mechanical property information such as yield strength, ultimate strength, and fracture toughness can be directly measured from such specimens if they are not smaller than size limits that are often based on characteristics of the material. At the other end of the spectrum are micromechanical type specimens that typically have dimensions of the order of 10's of microns and must be fabricated and tested in specialized equipment. In between this size range there are specimens and test methods that measure bulk response, but it is not a typical mechanical property measurement. This presentation will provide a review of test techniques on the larger end of the size range that tend to produce bulk property measurements.

Focus Session 2: Radiation Damage and Material Limits / 93

Post Irradiation Examination of an Alloy 718 Beam Window

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Alloy 718 is commonly used as a vacuum beam window for numerous high energy accelerator-based facilities. Specifically, at Los Alamos National Laboratory, it is used for the Isotope Production Facility and the Lujan Center at the Los Alamos Neutron Science Center. Recently, the beam window for the Isotope Production facility was replaced after 5 years of operation. To determine the usable lifetime, post irradiation examination of the window was performed at the LANL Chemical Metallurgy Research Building's hot cells. Optical images and dimensional measurements were performed. Then, 3 mm diameter disks were cut from the window to assess its mechanical properties using shear punch testing and microstructural analysis was performed using TEM. These mechanical property and microstructural measurements are compared to previous measurements on irradiated alloy 718 to assess the irradiation history and expected lifetime.

Summary:

Details of changes in mechanical properties correlated with microstructure are presented on an alloy 718 window irradiated to a total maximum calculated dose of 12.5 dpa.

Focus Session 2: Radiation Damage and Material Limits / 120

Discussion-Radiation Effects

Focus Session 3: Target Facility Simulation Challenges / 26

Magnetic horn design optimization for nuSTORM

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The magnetic horn, invented by Simon van der Meer over 50 years ago, has been used in essentially every neutrino beam line since its invention. Analytical calculation and some simulation work has been applied to horn design over the years. In this paper we show how, for the first time, computer-automated horn design optimization can be studied for implementation in a pion beam line like that in nuSTORM. The simulation uses new coding concepts and a massively-parallel computing environment.

Focus Session 3: Target Facility Simulation Challenges / 35

Beam-Induced Effects in Targets and Uncertainties in their Modeling

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Depending on material, level of energy deposition density and its time structure, one can face a variety of effects in materials under irradiation. Corresponding classes of radiation effects are defined with typical examples given. The dominant mechanism of structural damage of inorganic materials is displacement of atoms from their equilibrium position in a crystalline lattice due to irradiation. The characterization of this effect in the major codes via displacement per atom (DPA) models is described. At accelerators, radiation damage to structural materials is amplified by increased hydrogen and helium gas production for high-energy beams. Uncertainties in modeling these effects for medium- and high-energy beams are analyzed. Activities towards linking calculated quantities and observed changes in critical properties of materials are discussed.

Focus Session 3: Target Facility Simulation Challenges / 56

Modified Moliere's Screening Parameter and its Impact on Calculation of Radiation Damage

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The Moliere approximation of elastic Coulomb scattering cross sections plays an important role in accurate description of non-ionization energy, DPA radiation damage etc. The cross section depends only on a single parameter that describes the atomic screening. Moliere calculated the screening angle for the Tomas-Fermi distribution of electrons in atoms. In this report, the screening parameter was recalculated using a more accurate atomic form-factor obtained from the self-consistent Dirac-Hartree-Fock-Slater computations. For relativistic particles, the new screening angle can differ from the Moliere approximation by up to 50%. At the same time it is rather close to other independent calculations. A simple parameterization of the updated atomic screening parameters is proposed. DPA and non-ionization energy-loss calculated using the Hartree-Fock atomic form-factor is compared against results based on the other atomic screening models. The sensitivity of radiation damage calculation on parameters of the Coulomb elastic scattering cross section is discussed.

Focus Session 3: Target Facility Simulation Challenges / 121

Discussion 1

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Focus Session 3: Target Facility Simulation Challenges / 37

MARS15 study of the Energy Production Demonstrator Model for Megawatt proton beams in the 0.5 – 120 GeV energy range

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A study of the Energy Production Demonstrator (EPD) concept - a heavy metal target irradiated by GeV-range intense proton beams and its prospective use for the energy production - is carried out. Tungsten, natural uranium, lead, and thorium target options are studied using the MARS15 code. Energy deposition and energy gain, DPA rate and its spatial distribution, materials testing volume, hydrogen, helium, and tritium production are simulated in the proton energy range from 0.5 to 120 GeV. Results obtained indicate that in the proton energy range of 2 to 4 GeV the energy production can be most efficient for the natural uranium EPD while the same range is also the most appropriate for the tungsten testing station. Based on the simulations, conservative estimates (not including breeding and fission of plutonium) suggest that the proton beam power of ˜6 MW is sufficient for the uranium EPD with produced power exceeding the power consumed by acceleration systems. Simulation results reveal that the thorium target is not efficient for the energy production purpose. The ANSYS thermal analysis of the target has also been carried out, with related opportunities and limitations identified. Possibilities of benchmark experiments with low-intensity beams are discussed.

Focus Session 3: Target Facility Simulation Challenges / 51

Towards the simulation of proton beam induced pressure waves in liquid metal using the Multiple Pressure Variables (MPV) approach

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The development of the liquid metal spallation target META:LIC (MEgawatt TArget: Lead bIsmuth Cooled) for the European Spallation Source (ESS) at the Karlsruhe Institute of Technology (KIT) is based on previously developed liquid metal targets such as MEGAPIE, MYRHA and IFMIF. Insights gained from the short pulse liquid metal targets at SNS and JSNS lead to increased sensibility towards undesirable effects of proton beam induced pressure waves. The current design of META:LIC includes dedicated design measures to limit the effects of these pressure pulses. These design measures are based on in the formation of internal free surfaces where the pressure waves are attenuated. In order to allow for effective simulations during the design process and to gain a more detailed understanding the Multiple Pressure Variables (MPV) method [1,2] is proposed. The MPV approach is based on a single time scale multiple space scale asymptotic analysis derived for subsonic flow by an asymptotic series expansion in the Mach-number. Distinguished are the flow and acoustic length scales resulting in three pressure contribution, i.e. thermodynamic, acoustic and dynamic pressure which are discretized on numerical meshes of different resolution. The acoustics involving sonic wave evolution is resolved on a very coarse mesh allowing for relatively large time steps which are often suitable for the flow simulation living on much better resolved numerical mesh. Effects on different scales are coupled by coarse to fine interpolation and fine to coarse averaging.
The presentation will discuss the need for pressure wave simulations based on the META:LIC target. Then the MPV method will be formally introduced and its application within the open source tool box OpenFOAM is shown. A series of validation cases will be used to demonstrate the advantageous features of the method and in particular that often no time-step limitation beyond those enforced by the fluid flow calculation are imposed by the acoustics. Finally work in progress referring to target simulations will be shown.

[1] Munz C.-D., S. Roller, R. Klein, K.J. Geratz The extension of incompressible flow solvers to the weakly compressible regime. J Computers & Fluids 2003; 32:173-96.
[2] Klein R. Semi-implicit extension of a Godunov-type scheme based on low Mach number asymptotics I: one dimensional flow. J. Comput Phys 1995; 121:213-37.

Focus Session 3: Target Facility Simulation Challenges / 67

LIEBE: Design of a molten metal target based on a Pb-Bi loop at CERN-ISOLDE.

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Co-authors: Cesare Maglioni [1]; Donald HOUNGBO [2]; Lucia Popescu [2]; Paul Schuurmans [2]; Tania De Melo Mendonca [1]; Thierry Stora [1]

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Future perspective for physics measurements at CERN-ISOLDE call for the use of molten metal targets to improve the yield of radioactive isotopes delivered to the experiments and better handle the high power density from the beam. CERN launched in 2012 an R&D project called Liquid Eutectic

Lead Bismuth Loop Target for Eurisol (LIEBE) to investigate the feasibility of testing on line a Pb/Bi loop target compatible with the present installations at ISOLDE. While ISOLDE will be able to deliver a maximum of 10 kW of beam power, the power density on target is comparable to those available in existing or future facilities as EURISOL.

The design of the loop has been performed in collaboration between SCK-CEN, CEA, PSI, IPUL, SINP and the prototyping phase has now started. All the key elements integrated in the design such as a heat exchanger to evacuate the high power deposited by the beam, an electromagnetic pump to ensure the circulation of liquid metal, an irradiation chamber and a diffusion chamber to allow a faster release of the produced isotopes have been studied in details and will be tested extensively before installation on-line.

This talk focuses on the development of the element of the liquid metal loop target, presenting the challenges due to the different constraints involved and introducing the solutions proposed. Finally, an overview of the results of preliminary tests will be presented.

Focus Session 3: Target Facility Simulation Challenges / 25

The development of new concept for CADS spallation target

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For Chinese-ADS project, the aim is to burn MA. The tens of MW spallation targets for CADS is necessary to provide enough neutron to drive the blanket of MA, which is not an easy task.The first issue of high power target is how to remove the heat by the proton beam of the high current density. For solid targets to be used widely, the heat removal will be limited by the heat conduction of the target material and convection-cooling.
If the heat deposited could be moved from the interaction zone between the proton beam and the target to other place, where the heat be removed in an easily handle device, thus the target will be cold in off-line. The heat removal of the target will beyond the limit of the solid targets. Based on the concept, the heavy metal liquid target with a beam window have been designed and operated, for example, in the operation spallation targets, the SNS's total heat power is 1.4MW. Here, the beam window will be a limit for increase the power of the proton beam.Thus, the heavy metal liquid target without a beam window (windowless HML target) becomes a candidate for the higher power target. However, for heavy metal liquid, the hydrodynamic effects will be a limit for increase the power, such as, the shock wave, hydrodynamic instability, Cavitations and Splashing.
We propose the concept of the gravity-driven Dense Granular Target, where the heavy metal grains are chose to produce enough neutrons and the temperature of the grains could be thousand degrees. The heat of the high power proton beam deposited in the heavy metal grains will be deal with off-line. Another important aspect is source availability and cost of operation, which is affected by radiation effects, other damages and the radio-toxicity. The gravity-driven Dense Granular Target have a potential to easy deal with these problems. So the gravity-driven Dense Granular Target would be a new concept for tens of MW spallation target.

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Discussion 2

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Focus Session 4: Target/Beam Monitoring & Instrumentation / 105

Proton beam monitors at JSNS of J-PARC

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We have developed a Multi Wire Profile Monitor system by using SiC wires to built reliable and long life profile monitor system at the JSNS in J-PARC.
In order to obtain two dimensional beam profile at the target of the spallation neutron source, it was developed that beam monitoring technique based on the activation technique by using imaging plate with remote handling devices. It is shown that the beam width obtain by the MWPM agreed with the result by the result by IP. To obtain beam halo status, beam halo monitors are installed in front of the mercury target. It is shown that the beam halo is completely controlled which has smaller than the allowable intensity having 1 W/cc in unit of heat deposition.Under the present beam monitor system, high power pulsed beam operation such as 1 MW can be performed with high confident.

Summary:

Multi wire profile monitor system and beam halo monitors utilized at the JSNS will be presented.

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Instrumentation Discussion 1

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Monitoring beam position at the NuMI target with a thermocouple system

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A new system, called the Beam Position Thermometer, was built to monitor the position of the proton beam just before the NuMI target. It tracks beam poisiton by measuring beam heating of a grid of wires, read out by thermocouples. It has been in operation since September 2013. The criteria were that the monitor had to have better than half-millimeter accuracy, it had to be robust and stable in the high-radiation environment - lasting the life of a target, and it had to make do with minimal utilities, as the mounting module for NuMI targets severely limits the possibility for extra feed-throughs. Over the 1.6e20 protons on target (0.1 MW-year of integrated beam power) that NuMI accumulated since installation, the device has provided stable monitoring of beam position with 0.1 mm accuracy.

Summary:

Operation of an unusual system for monitoring the position of high power beams in a high radiation target hall.

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The Radiochemical Detector

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We present the concept for a radiation detector based on measuring the reaction products from a multiple-component fluid exposed to radiation. This detector will be useful for long-term measurements in high-radiation areas where other detector technologies may not survive. The approach uses a gas or compressible liquid composed of reactants that are predominantly stable in standard conditions, but react when exposed to radiation. The reactant gas is flowed through the measurement location and the products measured continuously with instrumentation removed from the radiation area. Furthermore, we show how a time-series measurement could be used to resolve the spatial distribution of radiation in a pulsed beam. Concepts for reactant gasses and product instrumentation will be described.

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Instrumentation Discussion 2 - Focus on New Techniques

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Integrating Safety into the LIEBE Pb-Bi loop target at CERN-ISOLDE

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CERN is developing a Pb-Bi target as a test for on-line production of radioactive beams at ISOLDE, to anticipate the increase of beam power that will be available after the connection of the new LINAC4 to the CERN injector complex. Beam power of up to 10 kW will become available, with power densities deposed in the target material comparable to facilities in the hundreds of kW regime.
The Eurisol collaboration for instance has endorsed this project as a step towards a full feasibility study of the 100 kW targets [1]. The project has been named LIEBE (LIquid Eutectic lead Bismuth loop target for Eurisol) and is being developed at CERN in collaboration with different institutes: CEA-Saclay, IPUL Latvia, PSI Villigen, SCK•CEN Mol, etc.
The LIEBE target project will demonstrate operation in a proton beam of 1.4 GeV/2 μA proton beam. Data will be collected during development, operation and post-mortem analysis to be used for future high-power target developments.
The different steps to assess the safety aspects of the future LIEBE target will be presented. As a first approach, the isotope inventory has been evaluated thanks to simulations in collaboration with CEA Saclay. The benchmarking of these results has been performed through the Pb-Bi samples

irradiation done at CERN and measured in collaboration with SINP - Kolkata. The data collected will be presented on a licensing approach basis in order to identify the potential difficulties for a future licensing process of an EURISOL direct (100-KW) target.
In parallel, a failure analysis has been performed on the proposed design to assess the potential failures and their consequences. This analysis is used to validate the number, type of monitoring and interlocks required during operation of the Pb-Bi loop target.
This presentation will give an overview of these different aspects and how they have been reflected in the design in order to guarantee a safe operation on the LIEBE target prototype. As a conclusion, some comparisons will be made between the LIEBE target and a 100-KW target.

[1] Ed. J. Cornell, "Final Report of the EURISOL Design Study (2005-2009) ", sept.2009

Summary:

CERN is developing a Pb-Bi target as a test for on-line production of radioactive beams at ISOLDE, to anticipate the increase of beam power that will be available after the connection of the new LINAC4 to the CERN injector complex. Beam power of up to 10 kW will become available, with power densities deposed in the target material comparable to facilities in the hundreds of kW regime.

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VIMOS, New Experience with a Dedicated Optical Safety System

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VIMOS is a dedicated safety system developed at the Spallation Neutron Source SINQ at the Paul Scherrer Institut, PSI, in Switzerland. VIMOS very directly monitors the correct current density distribution of the proton beam on the target by sampling the light emitted from a glowing mesh heated by the passing protons. The design has been optimized for obtaining maximum sensitivity and timely detection of beam irregularities relying on standard well-proven components. Recently it has been demonstrated that technical boundary conditions like radiation level and signal strength should allow for upgrading the system to a sensitive diagnostic device delivering quantitative and image-resolved values for the proton current density distribution on the SINQ target. By determining the temperature of the glowing mesh from the signals in two separate wavelength bands the temperature distribution over the mesh can be derived und subsequently the incident proton beam current density distribution. Work aimed at investigating the feasibility of adding these diagnostic abilities to VIMOS had shown promising results. After actual installation, unexpected difficulties concerning the long-term stability and –calibration related to attenuation and scattering in the light guide surfaced. Lessons learned and first results obtained with the currently working back-up solution relying for diagnostics on a sole infrared channel will be reported.

Summary:

sometimes only "plan B" appears to work

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Experience with the SNS* Target Imaging System

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The Target Imaging System (TIS) shows the size and position of the proton beam on the SNS Target which is coated with Cr:Al2O3 layer that luminesces where the proton beam hits. The light from this coating is transferred through mirrors and optical fibers to a digital camera outside the high radiation area. The TIS is used during operations to verify that the beam is in the right location and does not exceed the maximum proton beam peak density. This paper describes our operational experience with the TIS and the results of studies on the linearity, uniformity, and luminescence decay of the coating.

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Instrumentation Discussion 3 - Focus on Target Protection with Introduction by Tom Shea

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Poster Session 2 and Fermilab Tours / 123

HPTW Poster Session 2a - Presenters are encouraged, but not required, to be present with their posters.

Includes all posters. Presenters are encouraged, but not required to be present with their posters.

Summary:

Includes all posters. Presenters are encouraged, but not required to be present with their posters.

Poster Session 2 and Fermilab Tours / 125

Tour Safety Briefing

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Poster Session 2 and Fermilab Tours / 126

Tour of MINOS Underground & MI-8 Facility: Groups A & B

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Tour of MINOS Underground & MI-8 Facility: Groups C & D

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HPTW Poster Session 2b - Presenters are encouraged, but not required to be present with their posters.

Focus Session 5: Target Facility Challenges / 98

Practical Experiences from Remote Handling in Fusion

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Between February and May 1998 the first ever remote handling campaign on a Nuclear Fusion machine was completed at the JET Joint Undertaking in Culham UK.
This 4 month campaign was followed by 6 more campaigns up to and including 2010 with durations varying from 3-18 months and requiring a total of more than 22,000 hours of remote operation.
Preparations for the first remote handling campaign were started in the late 1970's and were at their zenith during the 4 years from 1993 to 1997. Preparations for each subsequent remote handling shutdown settled to a routine pattern of c12-24 months depending on the amount of new tooling and operational procedures required to develop.
Whilst the Remote Handling campaigns were all successfully concluded there were various unexpected interruptions to the operations as a result of problems with the condition of the plant, the conditions of the working environment and also failures of the Remote Handling equipment.
The overall experience gained has addressed most, if not all, of the elements vital to the successful implementation of remote handling based maintenance and modification for fusion plant and revealed the full extent of the competences and technologies needed for remote maintenance of similarly complex scientific plant.
This knowledge base is now being transferred to the ITER project through the European contribution managed by Fusion for Energy. The pertinent elements of the experience is also being transferred to other nuclear based sectors utilising or expecting to utilise remote handling.
The author was manager of the JET remote handling team from 1984 to 2006 and aims to provide a commentary on the practical experiences gained and their possible relevance to the maintenance of High Power Targets.

Focus Session 5: Target Facility Challenges / 44

The IFMIF/EVEDA Target Facility Design – From CDR to IIEDR

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The first wall of a fusion power reactor is subjected to an intense flux of 14 MeV neutrons causing a damage of up to 200 dpa and a high He concentration in a ratio of 10 appm/dpa. Since the onset of fusion reactor designs, a dedicated irradiation facility is considered to be indispensable for the development and qualification of materials. As are result design studies and irradiation experiments to simulate the embrittlement caused by fusion neutrons have indeed a long history. The concept is based on a high current, rather low energy deuteron source impinging on a liquid lithium target to exploit the neutron stripping effect, which yields a forward peaking flux distribution. In 2004, a quite consolidated conceptual design of the International Fusion Materials Irradiation Facility (IFMIF) was

achieved and documented in the Comprehensive Design Report (CDR). From 2008 to 2013, the design was further developed within the IFMIF/EVEDA project in a European/Japanese collaboration resulting in an Intermediate Engineering Design Report (IIEDR).
The contribution describes the evolution of the design of the lithium target facility in this phase starting from the CDR-concept. Whereas the beam-target interaction conditions remained almost unchanged, some important modifications were implemented in the loop design with regard to the target assembly outlet, heat removal system and the purification and maintenance concept. These changes are assessed with respect to their technical merit, implications for the building and other systems and their impact on the operation.

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The remote handling maintenance process of IFMIF target assembly

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The International Fusion Materials Irradiation Facility (IFMIF) is the most promising machine designed for testing candidate structural materials for fusion nuclear power reactors up to a damage rate of 100 dpa in five years. Materials are tested by using a high-energy neutron flux produced by a stripping reaction of two D+ beams impinging on a free surface liquid lithium jet flowing in a concave backplate on the Target Assembly. The Target Assembly is the most heavily exposed component to the neutron flux, since it is located in the most severe region of neutron irradiation (50 dpa/fpy), and then it has been designed to be exchanged remotely. Two design options of the target system were developed: the so called Integral Target, in Japan, and the one based on the replaceable backplate bayonet concept in Europe. The first target concept foresees the replacement of the entire target assembly from the test cell with a new one. For the refurbishment of the second target concept two potential approaches have been investigated: the first relies on the possibility to perform the entire refurbishment of the target assembly inside of IFMIF test cell cavern while the second one foresees to perform its refurbishment off-line in a dedicated hot cell.
The refurbishment process of the target assembly is a rather complex activity which requires sophisticate remote handling technologies and tools. It consists of a number of remote handling tasks and, among these, the backplate replacement, the cleaning of surfaces from lithium solid deposition, the inspection and repair of components inside of the target body and the diagnostics substitution are considered critical. In fact to fulfil the stringent requirement of IFMIF plant availability (today fixed at 70%) all these refurbishment operations have to be performed during the annual shutdown of the facility within a period of one week.
In the poster/presentation the remote handling maintenance activities performed, with both target assembly concepts, are discussed together with the outcomes of the preliminary tests carried out and with the design solutions adopted to optimize the entire refurbishment process of this component.

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Activated Waste Reduction and Design for Remote Maintenance

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The Facility for Rare Isotope Beams (FRIB) is a new national user facility for nuclear science, funded by the Department of Energy Office of Science (DOE-SC) Office of Nuclear Physics and operated by Michigan State University (MSU), East Lansing, USA. FRIB will provide intense beams of rare isotopes that are produced by the interaction between a heavy ion beam and a rotating carbon target. The heavy ion beam power will be 400 kW at 200 MeV/u. The interaction between the ion beam and target will produce high energy secondary radiation that cause the beam line components to become highly activated. These components when repaired or replaced generate a waste stream of activated materials that must be properly managed.
Reduction of the waste stream is a design focus for the FRIB beam dump and target. Reduction by design makes economic sense when the estimated cost of a waste shipment can exceed $ 300K. It also makes operational sense as waste cask availability may be limited and the availability of a waste disposal site is not guaranteed. Reducing the waste stream however adds complexity to the design and complicates the remote maintenance procedures. In this talk, we will discuss how the FRIB target and beam dump designs have evolved to minimize the activated waste stream consistent with remote maintainability.
This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University.

Summary:

The talk will discuss the FRIB experience with regards to tradeoffs between reduction of an activated waste stream with design complexity and ease of remote handling.

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Discussion on remote handling

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Handling ESH Issues of a Water-cooled Proton Beam-on-Liquid Lithium Stripper Film Experiment

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This paper reports the ESH Issues, and how they were resolved, to enable a water-cooled proton beam-on-liquid lithium stripper film experiment to be safely conducted. The Facility for Rare Ion Beams (FRIB) currently under construction at Michigan State University (MSU) will accelerate all ions, up to uranium, to an energy of 200 MeV/u with beam power up to 400 kW. To increase the charge state of the ions and reduce the number of accelerating modules in the linac, a charge stripper is needed that can strip uranium ions from, for example, the charge state 33+ to 78+. Developing the charge stripper for such an intense uranium beam is a severe technological challenge; the leading design choice for this stripper is a thin, high speed, liquid lithium film of thickness ˜10 μm and the uranium beam will deposit about 700 W in the film while passing through and losing about 2% of its kinetic energy. Previous R&D at Argonne National Laboratory (ANL) has demonstrated the stable formation of such a film, but prior to the work reported here, the film has not been tested with beam.

To provide a suitable proton beam for thermal testing of ANL's liquid lithium stripper film, a water-cooled ion source, originally built for the Low Energy Demonstration Accelerator (LEDA), was borrowed from Los Alamos National Laboratory (LANL) and moved to MSU where it was re-commissioned after a new beam transport system, comprised of two intermediate water cooled collimators, was built and installed. The re-commissioned ion source was then moved to ANL and mated with Argonne's lithium stripper system, where the proton beam deposited in the lithium film a power density comparable to 30 % of the maximum power density expected at FRIB when accelerating 400 kW of U at 200 MeV/u. Video of the beam-on-film test will also be discussed. Because the protons only penetrate the first 1.5 μm of the lithium film's 10 μm thickness, the net effect, in that first 1.5 μm of the film, is a power density higher than FRIB by a factor 2. Hence, a stripper based on this liquid lithium technology is now the base-line design choice for FRIB.

This research was supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661.

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NuMI Target Hall Reconfiguration for NOvA

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To meet the needs of the NOvA experiment at higher beam power (700kW), the NuMI target facility had to be reconfigured from the low energy to the medium energy neutrino configuration. One of the main requirements was relocating NuMI Horn 2 nine meters downstream of its existing position. This involved significant reconfiguration of the existing steel shielding and the overall target-hall operational layout. Given the high residual dose rates, this was a very high radiation job that required careful planning and mitigation techniques. The resulting reconfiguration went exceptionally well with roughly half the radiation exposure than predicted. Experiences from this reconfiguration work together with other NOvA-related target hall infrastructure upgrades will be presented.

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Target chase: Pros and Cons of different technical solutions

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Discussion on Target facilities challenges

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Closing Plenary Session / 134

Closing Plenary Presentation

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